Beam collimation in the transfer line from 8 GeV linac to the Main Injector

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phase advance per cell (ψ)	dispersion (η)	$dX = \eta \cdot dP/P$	β_x	$3\sigma_x$	beam line length
degree	m	mm	m	mm	m
Two-wave dispersion beam line					
45	8.88	10.0	69.0	8.1	585.75
60	8.85	10.0	76.9	8.5	560.88
90	8.80	9.9	110.2	10.2	528.76

The beam transfer line from 8 GeV Linac to the Main Injector is based on a periodic FODO structure with phase advance of 60 degree per cell. As shown in the table this lattice has sufficiently less maximum beta-functions for the same amounts of dispersion and total length. This is an advantage for off-momentum collimation.

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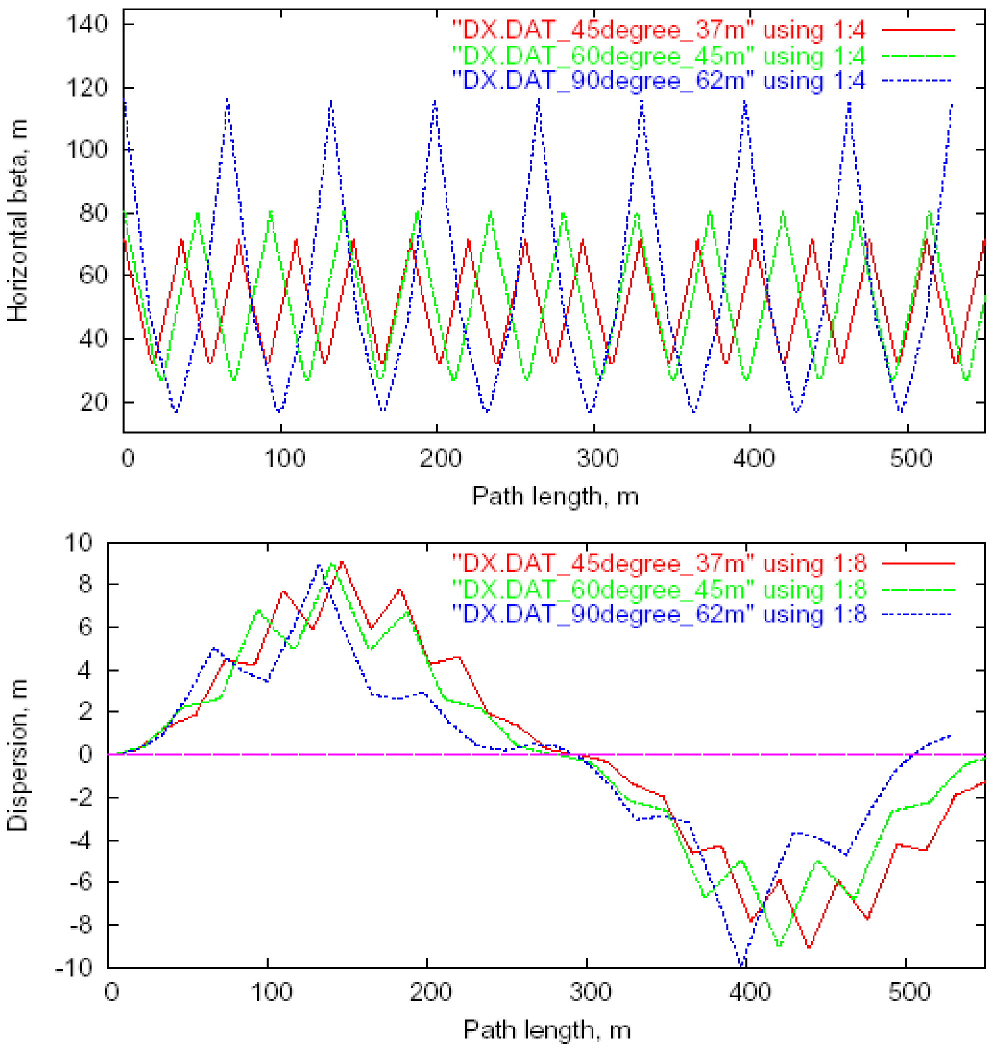

Horizontal beta function (top) and dispersion (bottom) in the 45, 60 and 90-degree phase advance per cell achromatic lattices. 16 cells of 45, 12 cells of 60 and 8 cells of 90-degree lattices are shown.

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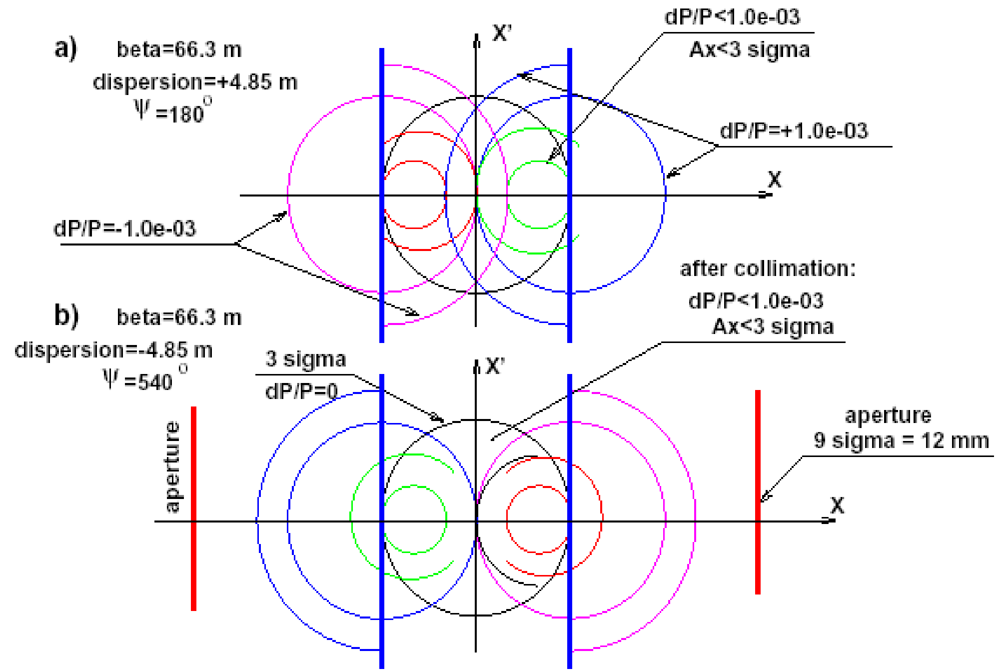
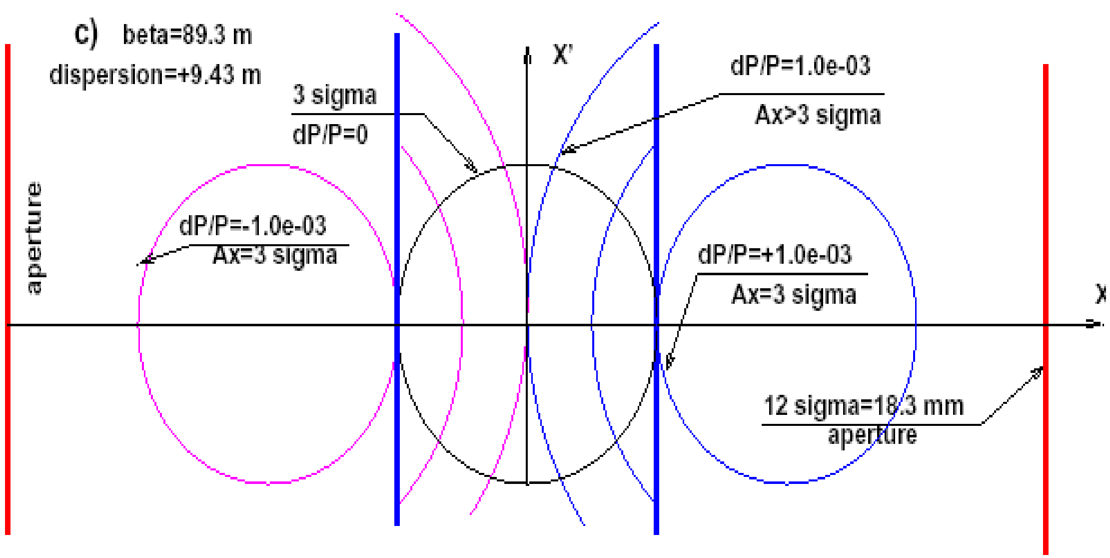
Top: off-momentum collimation in two locations of beam line - with positive and negative dispersion. Bottom: collimation in one location of beam line. Minimal horizontal aperture of the elements is equal to 6 sigma in the first case, and 9 sigma in the second one. If one assumes a distance between the

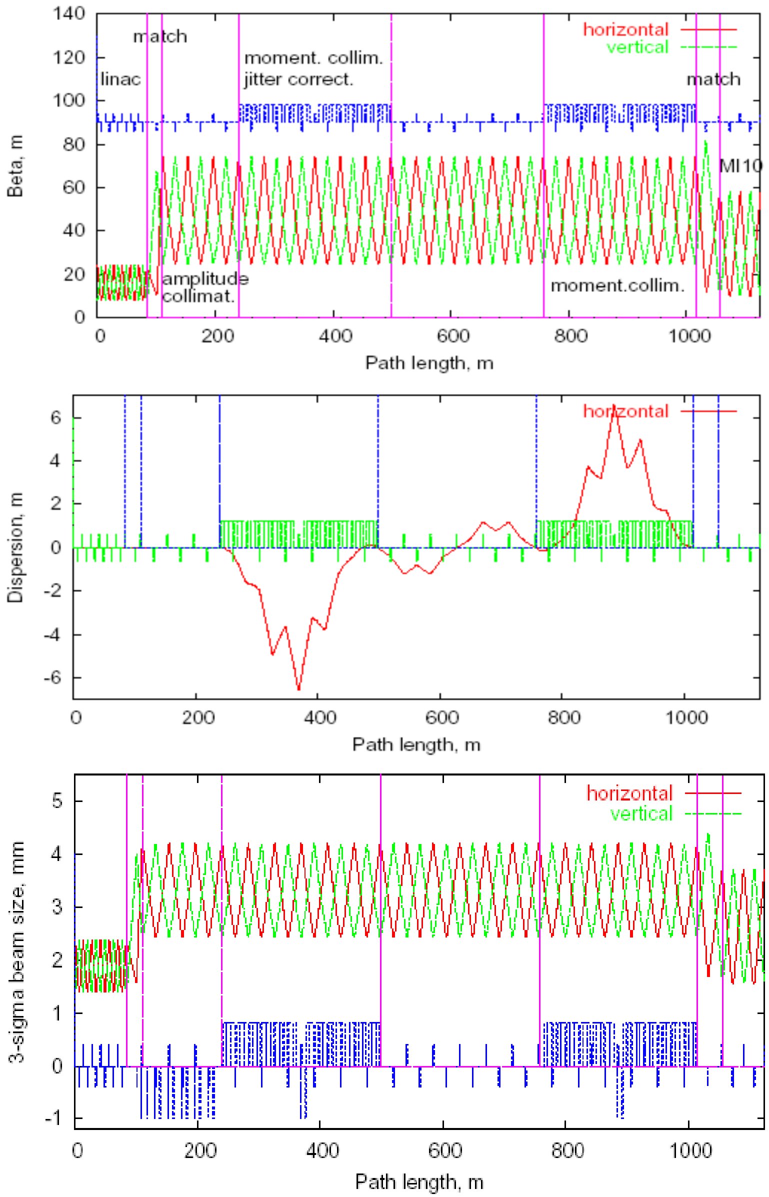




beam pipe and the edge of the beam equal to 3 sigma, the required radius of aperture is equal to 9 sigma in the first case, and 12 sigma in the second one.

phase advance per cell (ψ)	beam emittance	dispersion (η)	$dX = \eta \cdot dP/P$	β_x	$3\sigma_x$	beam line length
degree	$mm \cdot mrad$	m	mm	m	mm	m
One-wave dispersion lattice						
60	6.0	19.8	22.3	115.3	10.4	420.66
60	1.5	9.43	10.6	89.3	4.58	313
Two-wave dispersion lattice						
60	6.0	8.85	10.0	76.9	8.5	560.88
60	1.5	4.85	5.46	66.3	3.97	467

Comparison of "one and two dispersion wave" 60-degree lattices for 95% emittance of 6.0 mm-mrad and 1.5 mm-mrad. "One-wave dispersion lattice" is used for off-momentum collimation by two stripping foils located at 3 sigma from both sides of the beam at only one place of the beam line. Displacement of off-momentum particles should be bigger than 6 sigma of the beam.



The beam line consists of matching section between Linac and FODO lattice (26.558 m), amplitude collimation (3 cells without bending magnets, 129.317 m), momentum collimation and jitter correction section (6 cells with dipoles, 258.633 m), straight section included for proper positioning of the Linac and beam line at the Fermilab site (6 cells, 258.633 m), second part of momentum collimation (6 cells with dipoles, 258.633 m) and matching section between FODO lattice and Main Injector MI10 straight section (40.68 m). The total length of transfer beam line is 972.454 m. The location of stripping foils and beam dumps are shown by a vertical bars directed down in in the bottom figure.

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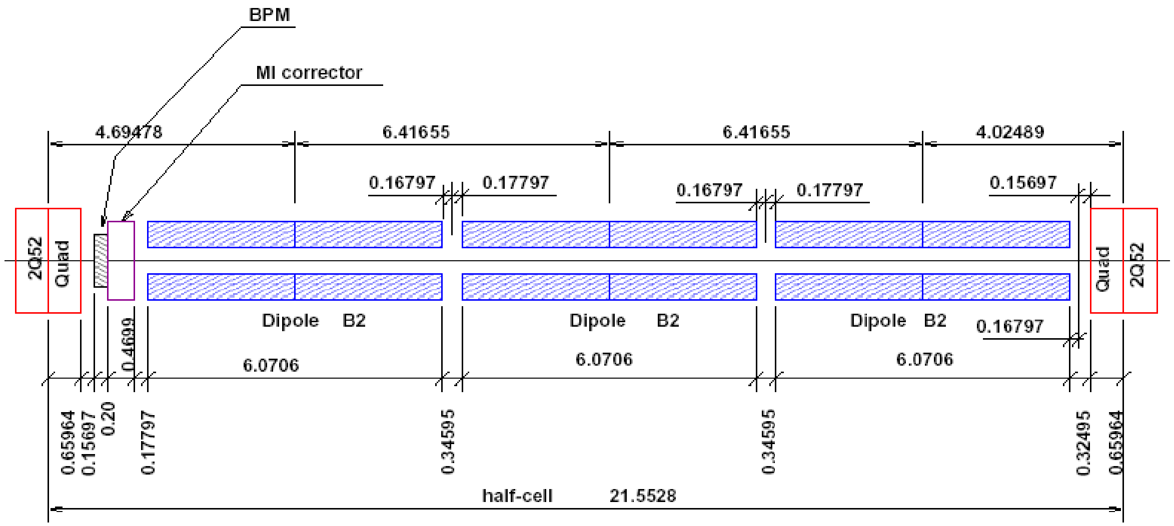

A final design of 8 GeV beam transfer line is done using the existing Main Ring dipoles B2 (aperture: 48mm X 23mm) and Main Injector horizontal and/or vertical correctors (gap aperture 48 mm).

The required strength of vertical and horizontal correctors in this lattice is equal to BL= 0.018 T-m. This corrector placed near a focusing quadrupole produces a beam displacement in the next focusing quadrupole of 38.1 mm. Dipole B2 field is as low as 0.05 T to prevent H(-) ions stripping by magnetic field. The bending angle of B2 magnet at Pc=8.88889 GeV is 0.010237 radian. The quadrupole aperture is D=79 mm. The quadrupole field at radius of 35 mm is 0.0373 T.

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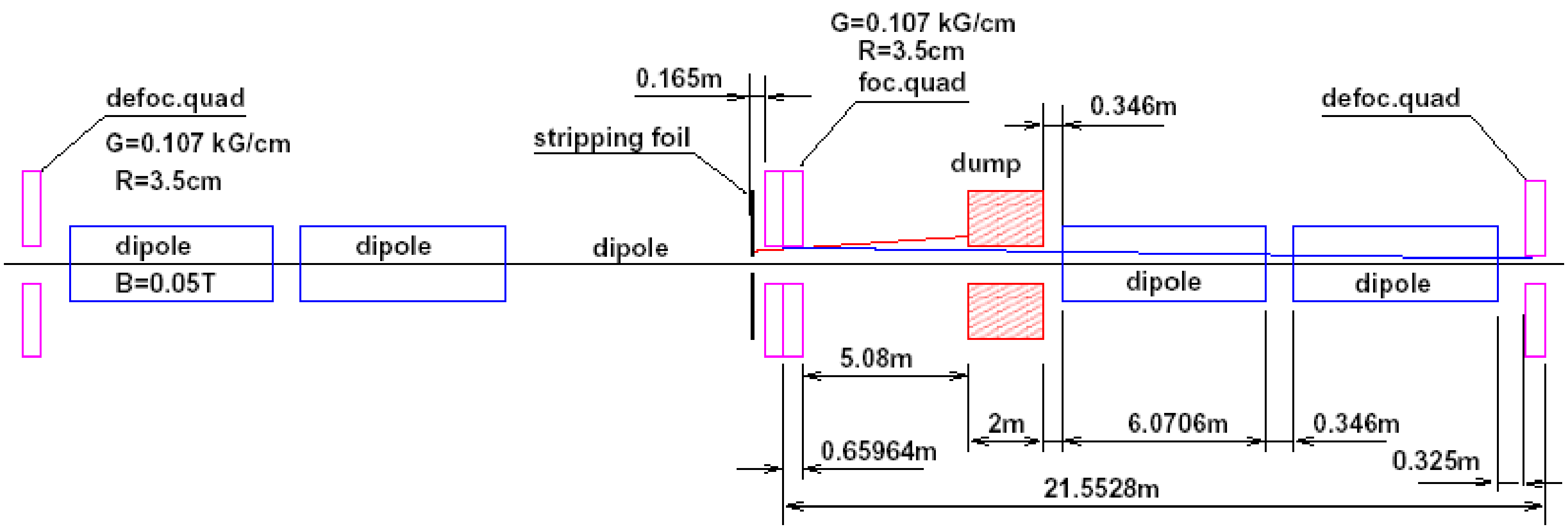

Halo collimation is done by stripping of H(-) ions at the foil located upstream of the focusing quadrupoles and then intercepting of H(o) atoms and protons by the beam dump located in 5 m behind the focusing quadrupole. Six foil-dump stations are used for amplitude collimation in the first six cells of beam line, and two stations in the positive and negative dispersion wave maximum for momentum collimation.

At these simulations the 95% emittance of initial beam, including halo, is equal to 4.17 mm-mrad (size of halo is a factor of 5/3 of the beam core size) and sigma of momentum distribution is 0.001. A 3 sigma of the beam (core) is 4.15 mm at the foils and 3.61 mm at the beam dumps. Collimation of the beam is done with amplitude foils and beam dumps located at 4.25 mm from the beam center. Momentum collimating foils and beam dumps are at 6.5 mm from the beam center. As horizontal dispersion at the foil is D=6.5 m, this provides collimation of the beam at dP/P=0.001.

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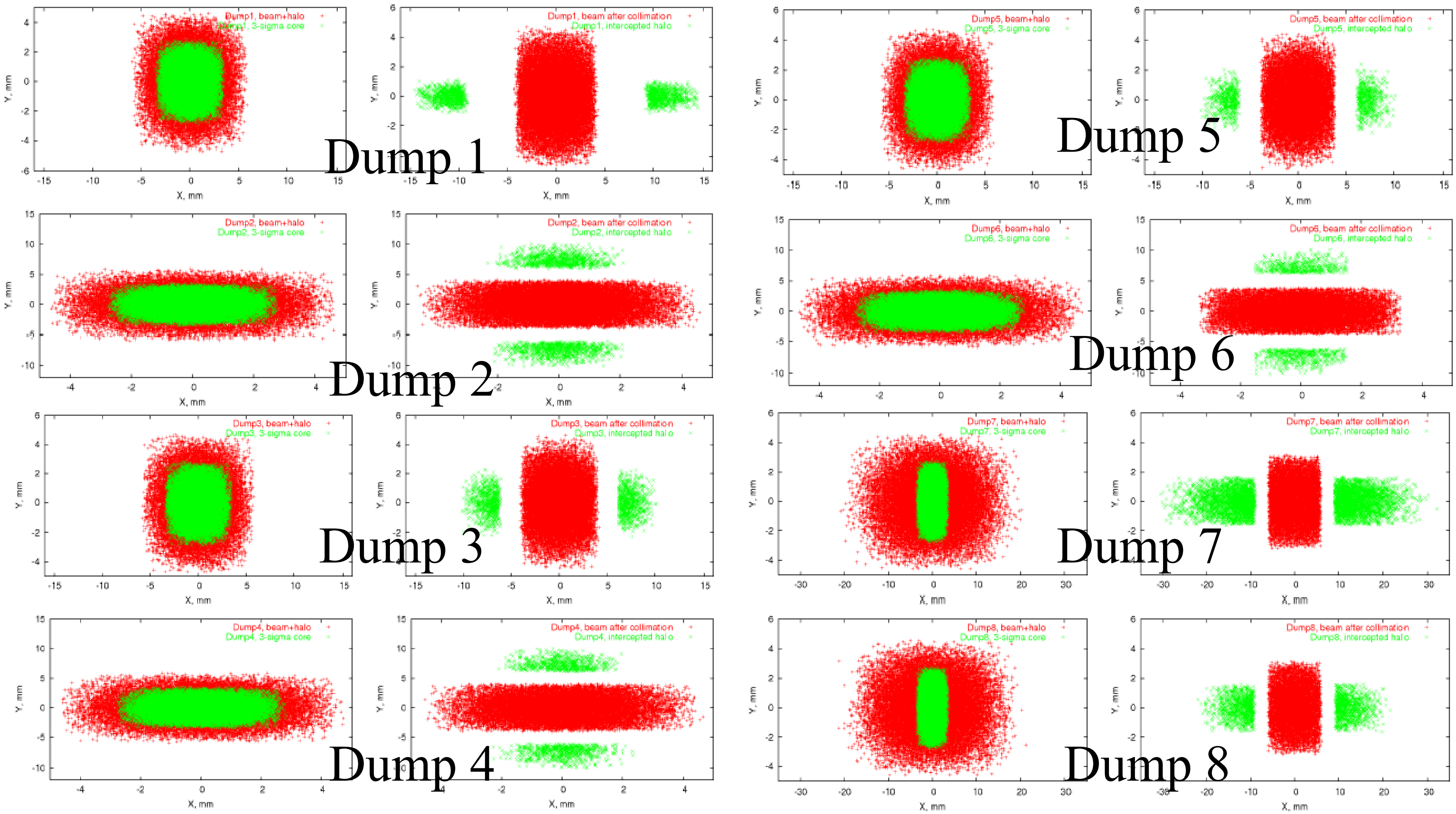

Left side figures: 3-sigma core of the beam (green) and beam without collimation (red). Right side figures: beam population after collimation at every 60 degree (red) and intercepted halo at the beam dumps (green).

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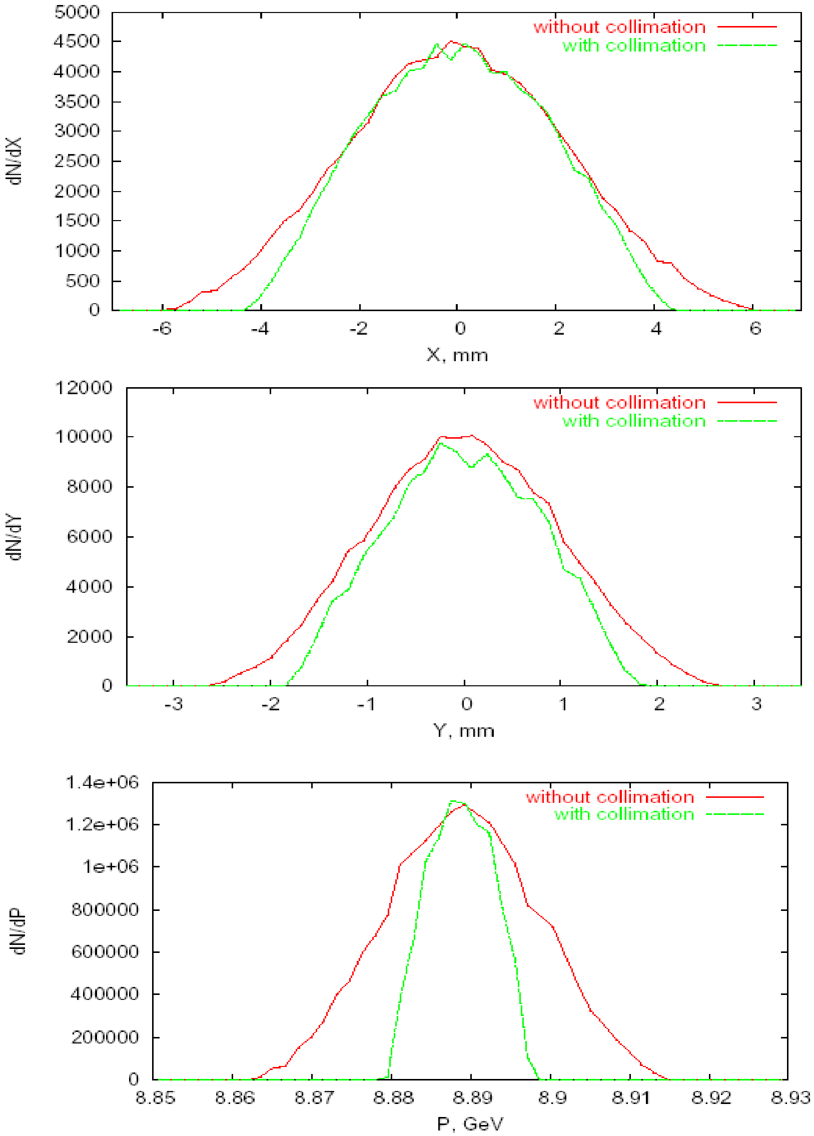
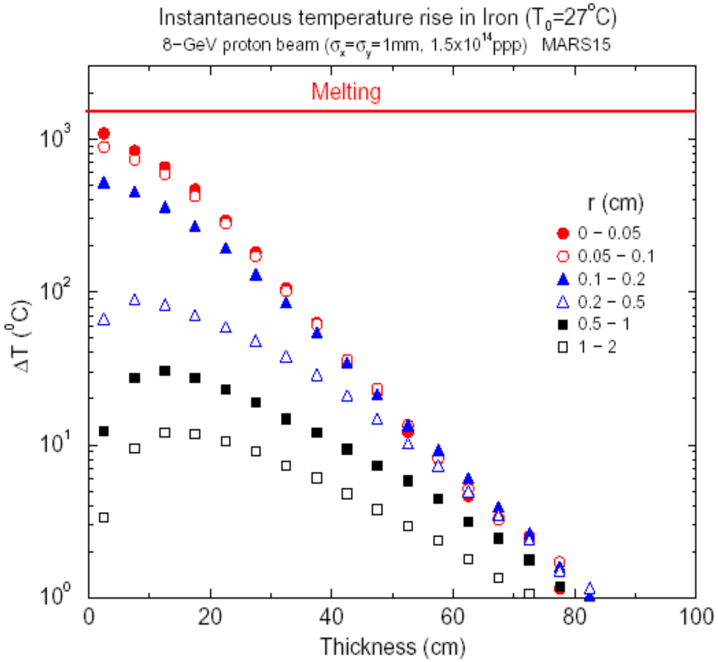
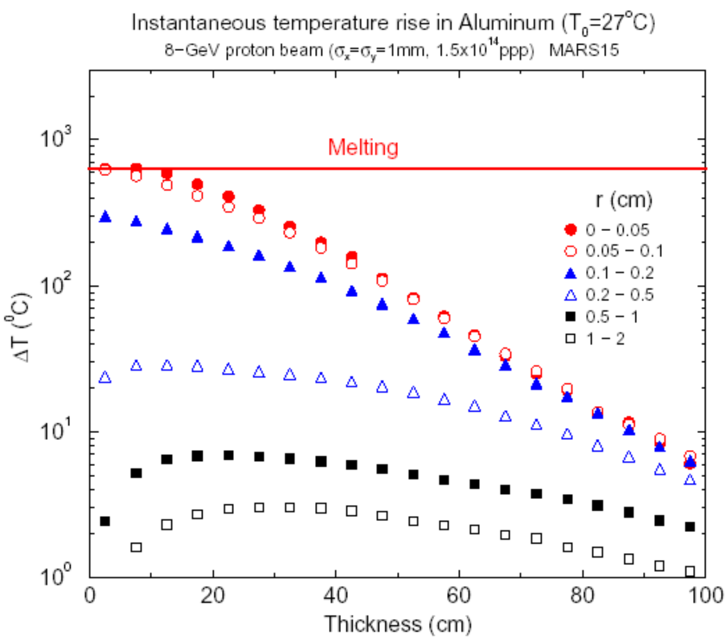


Calculated horizontal, vertical and momentum distributions of the beam without and with collimation at the entrance to the MI-10 straight section of the Main injector.





The MARS15 calculations on instantaneous temperature rise per a single pulse of 1.5e14 protons accidentally lost in iron and aluminum collimators. The iron collimator withstands a single pulse but is melt if the next pulse arrives. Aluminum collimator melts after a single pulse. If follow the SNS policy that the collimator should withstand two pulses in a row, than the optimal solution would be a 0.5-m long and 10-mm radially thick graphite insert in 1-m long steel collimator.

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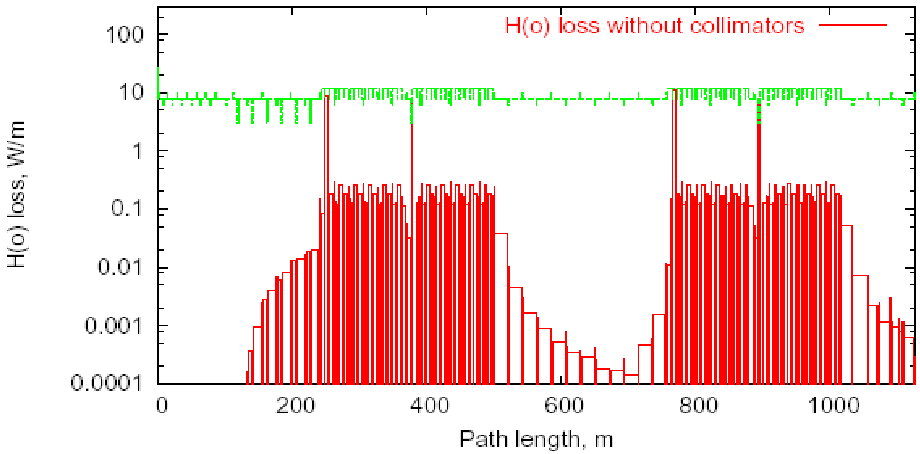

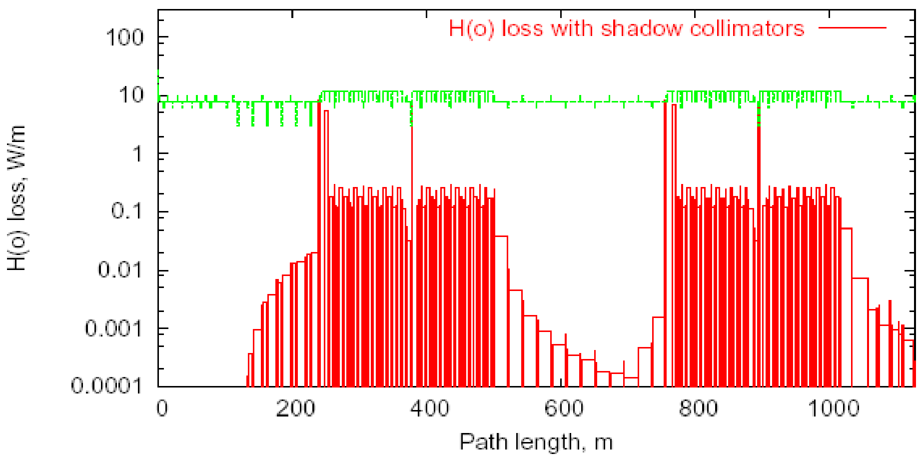

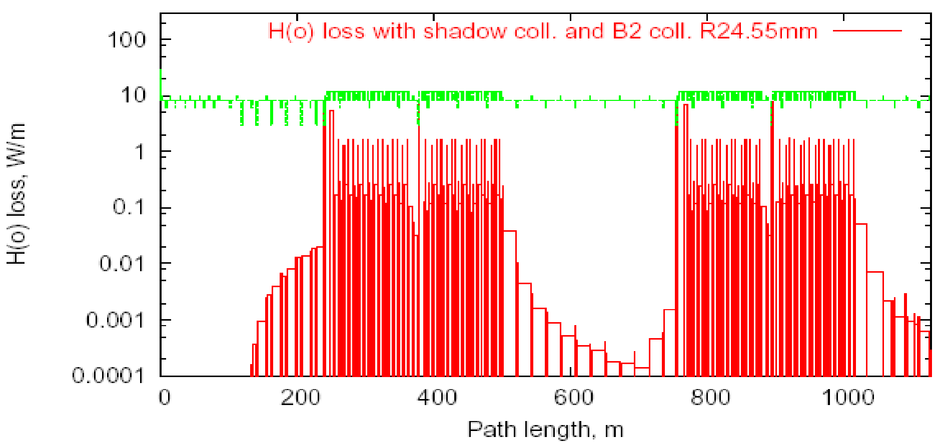

There are three major mechanisms for 8 GeV H(-) ions stripping blackbody radiation (i.e., thermal pho-tons), magnetic field and residual gas. The calculated stripping rates are:

Residual gas at 1e-07 torr : 3.2e-07 1/m
Magnetic field at 600 Gauss: 3.0e-071/m
Blackbody at 300 K: 5.3e-07 1/m.

The total loss rate inside the bending magnet (worse case) is about 1.2e-06 per meter. H(o) loss along beam line without H(o) collimators (top), with 2 shadow collimators upstream of the bend regions (aperture 13 X 13 mm-mm) (middle) and with internal collimators inside the B2 dipoles are shown. The stripping rate of 1.2e-06 per meter is assumed everywhere along the beam line.

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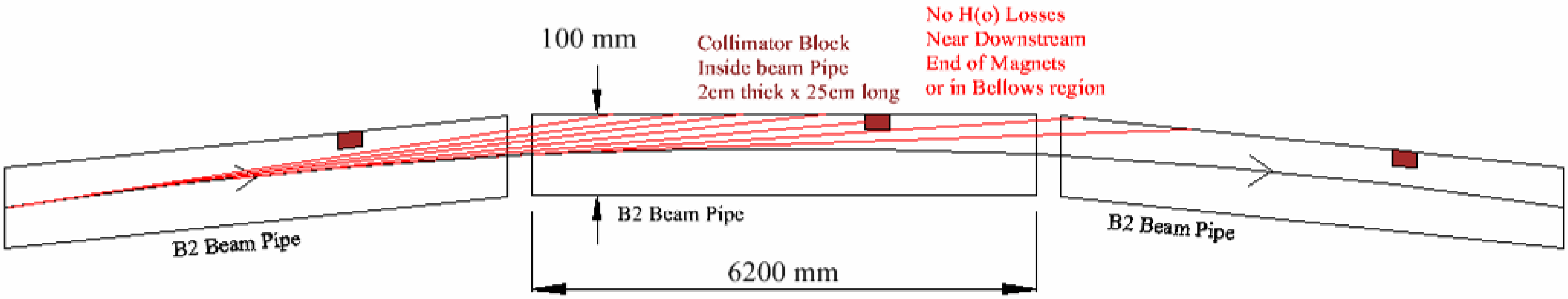
B2 Beampipe Internal H(o) Collimator Concept



- **The idea of the H-zero collimator is to get the H-zero losses from blackbody radiation to shower up deep inside the body of the magnet, but not in the interconnect region or near the downstream end where it will irradiate the interconnect region.**

- **It doesn’t have to be a great collimator – we are only looking for a factor of 5-10 to make the activation of the magnet end regions less of a problem.**

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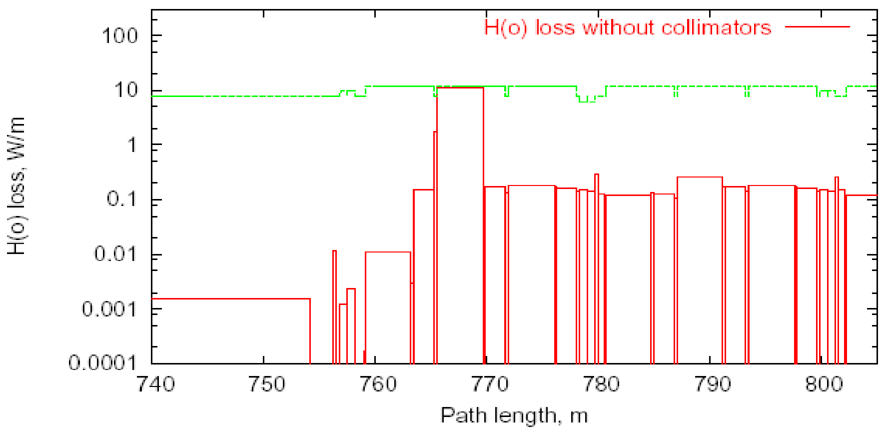
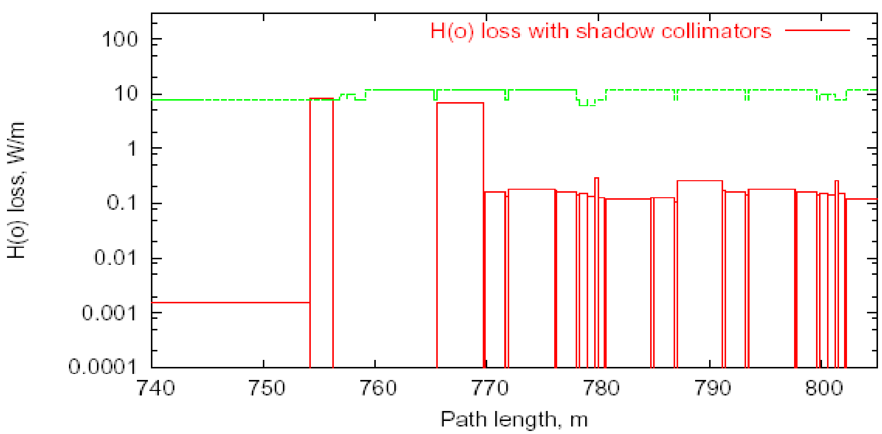
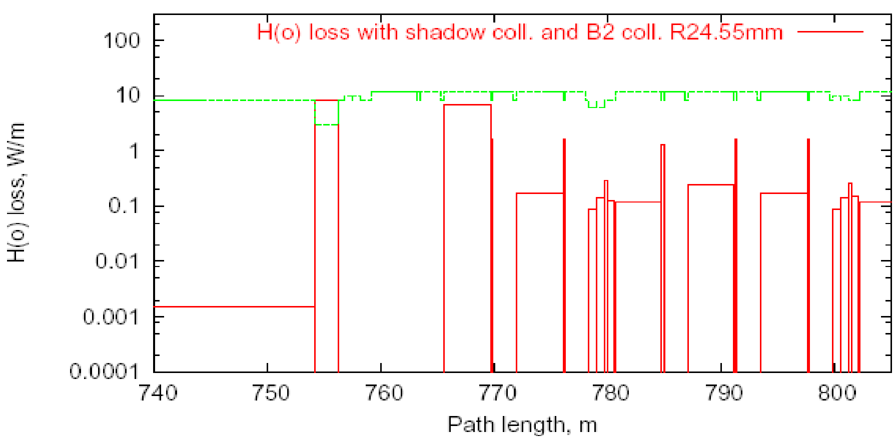
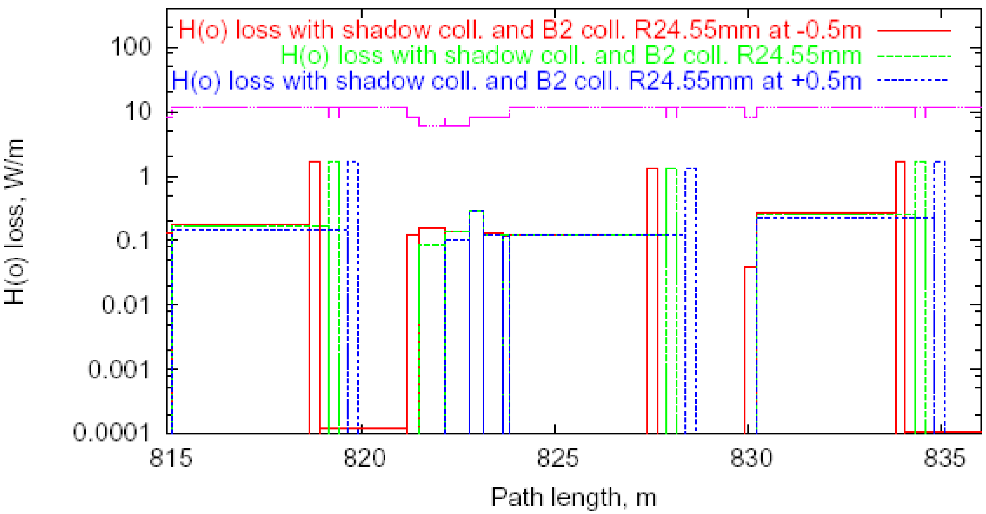




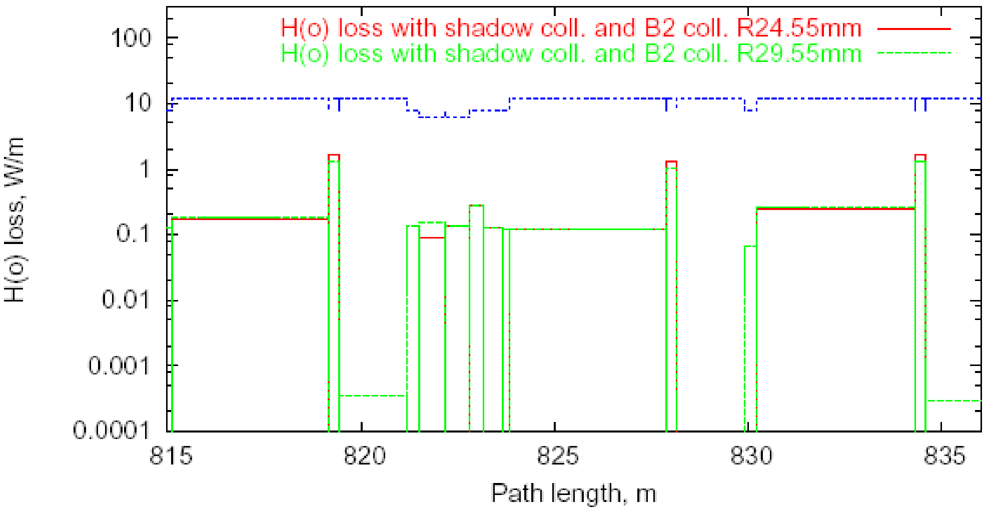


H(o) loss along beam line without H(o) collimators (top), with 2 shadow collimators upstream of the bend regions (middle) and with internal collimators inside the B2 dipoles (bottom) are shown.

The shadow collimators located upstream of the bend region protect only first dipole and not effect losses at the other ones. The B2 internal collimators decrease H(o) losses at the last 2-m region of the magnet body by more than three order of magnitude.



H(o) loss along beam line with internal collimators inside the B2 dipoles located at 2.5 m, 2 m and 1.5m upstream of the dipole end.



H(o) loss with horizontal aperture of internal B2 collimator of 24.55 mm and 29.55 mm

Conclusions

The transfer beam line is based on a periodic FODO structure with phase advance of 60 degree per cell. This lattice has sufficiently less maximum beta functions for the same amounts of dispersion and total length compared to 90-degree lattice, that is an advantage for off-momentum collimation.

Halo collimation is done by stripping of H(-) ions at the foil located upstream of the focusing quadrupoles and then intercepting of H(o) atoms and protons by the beam dump located in 5 m behind the focusing quadrupole. Six foil-dump stations are used for amplitude collimation, and two stations in the positive and negative dispersion wave maximum for momentum collimation. Collimation of the beam is done with amplitude foils located at 3 sigma and beam dumps at 3.5 sigma from the beam center. Momentum collimation is done at dP/P=0.001.

The iron beam dump withstands a single pulse of accidentally lost 1.5e14 protons but will be melt if the next pulse arrives.